Comparative study of emerging rooftop photovoltaic for urban greenery

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Abstract

This paper present short review the significant studies in the area of urban greenery using rooftop photovoltaic. The recent development in this field is being covered, its shortcomings being qualitatively analyzed so that future strategies may be drawn for systematic inclusion. Few emerging techniques for rooftop photovoltaic systems are presented and analyzed on both economic and technological fronts. A cost effective prototype is presented at the end for advance applications in urban areas with IoT-compatibilities.

Introduction

Two technologies gained considerable attention for environmental safety in recent times amid expanding urbanization. One refers to the green roof concept that promises energy conservation by improving building thermal performance. The other one, integrating the photovoltaic (PV) systems on rooftops as a source of renewable energy for urban buildings. The limited roof space, however, makes these two technologies a competitor for each other. The emerging fact is that these two can get integrated to offer a more conducive environmental friendly solution. The results have shown that more advantageous offerings come using integrated rooftops green photovoltaic due to cooling and shading effects. The evapotranspiration caused by roof greenery further enables higher efficiency by photovoltaic panels, in turn, shades due to panels protect plants from excessive sun heat and evaporation. This mechanism enables improved plant growth and efficient photovoltaic energy for the buildings. The initial studies were focused on evaluating performance analysis for green roofs and photovoltaic separately. The beneficial integrated technology, however now gaining interest among researchers and developers. The advantage of this emerging technology is pivotal for the subtropical counties like India where we get the best of the sunlight exposure.

Principle of operation

The green roof for a building refers to the rooftop that is partially or completely get covered by plants with growing medium over the waterproofed roof slab as depicted in figure 1. The outdoor climatic factors such as solar radiations, temperature, humidity, wind flow, *etc.* improve due to green roofs.

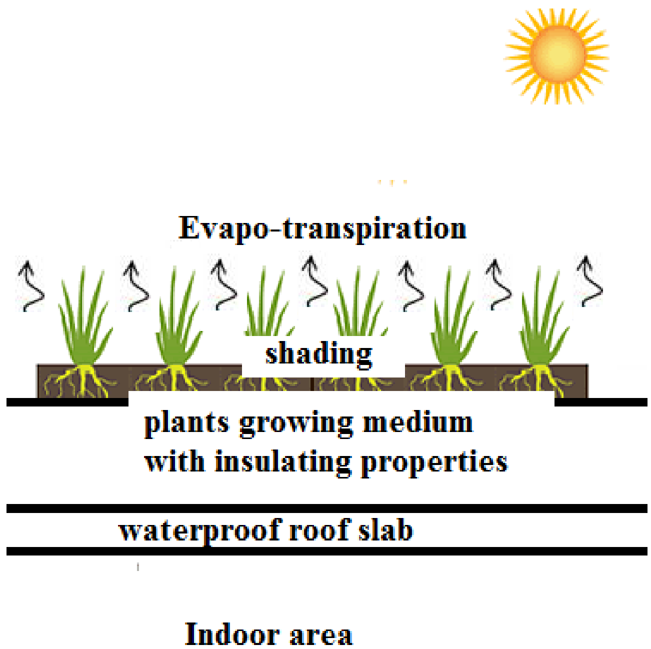

Figure 1 Thermal mechanisms for green roofs.

Solar energy gets absorbed that helps in the growth of plants due to improved photosynthesis, transpiration, evaporation, and respiration. The internal benefit to the building lies in the fact that it reduces the roof surface temperature that in turn, decreases the energy requirement. The external benefit is that this decreases the outdoor urban temperature indirectly improving the surrounding environment. The efficiency of roof mounted photovoltaic panels depends on solar irradiations. The high temperature, however can decreased the efficiency because of increased carrier recombination rates due to increased carrier concentrations. The productivity loss due to temperature increase is found to be as high as 25%, therefore, heat is the primary concern for roof mounted photovoltaic panels. The linear dependence is found for power loss from photovoltaic cell due to surface temperature increase [1]. A typical solar cell coverts only 6-20% of incident solar energy to electricity rest goes away as heat. This excessive heat can be extracted from

photovoltaic module using flow of water or air beneath module through thermal collectors. Another deteriorating factor is air pollution that causes dirt and dust to get mounted on PV module surface and partially block the sunlight, hence results in reduced output. A significant impact on PV efficiency is found as high as 20%, due to air pollutants [2]. Such performances, however depends on atmospheric conditions so cannot be generalized.

The integrated technology for green photovoltaic (*i.e.* green roof and solar PV) initially reported by Kohler *et al.* [3], as illustrated in schematic shown in figure 2. The initial idea was appreciated due to promising results as good as 6% higher than conventional roofs. The green ambient around solar PV panels create cooler atmosphere at reduced dust levels so that it work better.

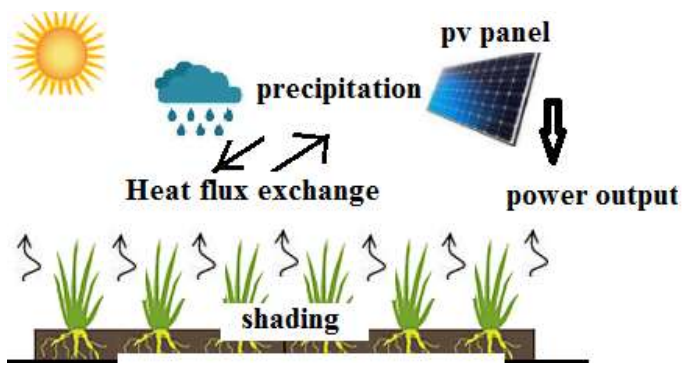

Figure 2 Integrated green roof photovoltaic panel.

The advantage of an integrated green roof is that it can reduce the ambient temperature between 0.3°C to 3°C based on regional climatic conditions and type of vegetation [4]. This enhances the performance of photovoltaic output. Increased efficiency of up to 3%, by using green roof photovoltaic is already been reported [5].

PV surface cooling

The unit rise in surface temperature of PV module beyond 25°C, causes a decreased efficiency, amounting in the range of 0.4 to 0.65%, therefore cooling the surface is very important for enhanced performance [6]. Kandeal *et al.* elaborated on the different cooling mechanisms that are being researched and developed by different groups in this field [7]. The liquid-based cooling mechanism may be subdivided into active or passive systems depending on whether we use a pumping system or not, respectively. The aero-based methods are either natural (without the use of fans) or forced (with fans or blower). The use of extended surfaces as fins and heat sinks can

also help in reducing the temperature furthermore, depending on materials and their configurations.

Passive cooling is easy and proven to be economical than active one as it does not require an extra pumping system. The generally used liquid for PV panel cooling is water due to its economical price, good thermal conductivity, and better heat capacity. Some groups added nano-particles to water, and obtain improved results [8]. Such hydro cooled PV system uses continuous intermittent water pumping. However, such techniques are found to be good for smaller applications such as houses. In an active cooling procedure, high water flow velocity improves the convection process and results in better cooling. The running cost of the overall system, however, increases due to additional power demand. Saxena *et al.* reported passive cooling with various mass flow rates such as 3, 5.3, and 6.2 L/min [9]. The energy output performance was found to get enhanced by a typical factor of 18% as compared to uncooled systems. If a continuous steady flow rate is maintained at 0.6 L/min then a 29% power increase is observed. Tashtosh *et al.* proposed active cooling using a pump, pipeline, sprinkler, nozzles, *etc.* [10]. The different positions were investigated experimentally and observations showed that the cooling procedure gives efficient performance compared to uncooled PV panels with the best-reported results at 37°C.

Even though the active method of PV module cooling gives better efficiencies but the cost is also on a higher side as compared to the passive method. This increased cost is due to the requirement of the pump and continuous monitor on the system that in turn also consumes power. The current literature indicates there are many cooling methods based on embedded controllers that are being investigated for enhanced outputs from PV modules. That is being done to get regulated surface temperature of PV modules by continuous monitoring and utilize it for irrigation purposes. The use of embedded systems as automated controllers have been reported, to overcome the problem of continuous monitoring. Some of the significant progress in this field is tabulated in table 1.

References	Controller	Response time	Efficiency	Estimated cost
Faraji *et al.* [11]	Xilinx XC3S400 (FPGA)	2.5 ms	98.8%	38$
Mohd Zainuri *et al.* [12]	DSP TMS320F28335	20 ms	95.2%	21.75$
Sekhar *et al.* [13]	dsPIC33fJ12MC802	2s	97.5%	18$
Soon *et al.* [14]	Micro controller PIC18f410	0.275s	99%	18$
Boukenoui *et al.* [15]	dSPACE 1103	0.264s	97.295%	38$

Table 1 Controller based monitoring systems for active cooling of PV module.

Proposed prototype

The easy-to-use Arduino UNO board could be utilized to make automated cooling systems for PV modules. It is an open-source hardware system powered by open-source software that does not need any external programmer. The IDE (integrated development environment) software is compatible with most of the operating systems like Linux, Windows, Macintosh, *etc.* This embedded system board does not require an external programmer *i.e.* burning procedure. This is also compatible with IoT (internet of things) applications. A more elaborated system design was pretended by Fuentes *et al.* [16] costing about 73$. Figure 3, shows the simplified schematic for the automated cooling system designed for the PV module using Arduino UNO embedded controller. That may be extended for irrigation purposes for rooftop gardens.

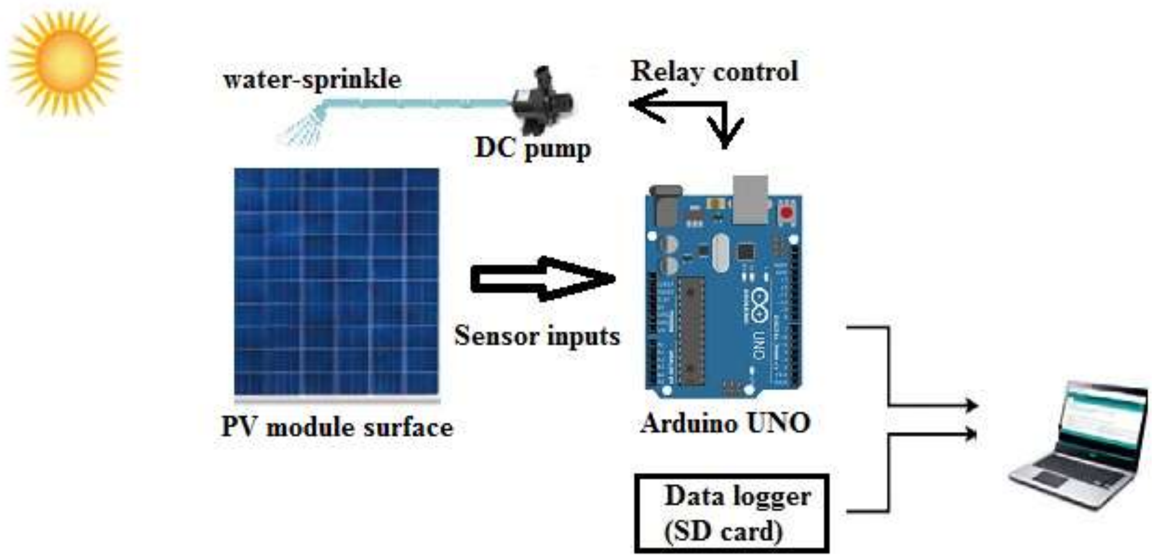

Figure 3 Prototype design for Arduino UNO based PV hydro cooling system.

The various sensors are used to monitor the performance of cooling systems like the voltage, current, temperature, etc. This data is fed to the controller board which is programmed to monitor and control the system. The relay switch is used to provide control for the DC water pump that sprinkles the water on the surface of the PV module and reduces the surface temperature. The output is monitored and compared with standard calibrated values to on/off the relay switch. The data logger (SD card) is used to store the data and help in further improving the performance under a variety of conditions as it may arise. The elaborated system design proposes an economical solution for the efficient use of rooftop photovoltaic greenery.

Conclusions

Rapid urbanization has depleted the green regions and that needs to get balanced with alternatives. This paper presented the importance of emerging photovoltaic green roofs in urban areas. It is found that this also increases the efficiencies of photovoltaic modules if properly calibrated. The emerging trends for the use of embedded systems in automated control and monitoring for green photovoltaic are also compared. The prototype for Arduino based system is presented as it is compatible to be used with IoT at a low cost. This design proved to be useful in irrigation while maintaining important environment parameter records through a data logger. The effective cost may be compromised to get benefits like wifi, Bluetooth, LAN, GPS, etc. compatibilities. The proposed design is suggested to be well suited for subtropical developing countries, like India.

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